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There are three types of disastrous risks from outer space that could cause harm on the Earth's surface: space debris, space weather and Near-Earth Objects (NEOs). Due to recent incidents including a number of large satellites re-entering the atmosphere, large solar flares and near-misses between Near-Earth Asteroids (NEAs) and our planet, our current space monitoring infrastructure cannot entirely rule out the risk of a disaster originating from space. Thus, we must verify any serious threat posed to humanity's existence and society's infrastructure.

Space Situational Awareness (SSA) has been the subject of great attention by experts in various fields in their efforts to raise a general awareness of the risks posed by the space environment and measures to counteract them. This goes beyond merely monitoring the space environment. Europe, the United States, China and others are hammering out policies that take SSA into account. However, the SSA concept itself has yet to take root in Japan. Although different organizations and research groups deal with the three types of space environment risk independently, their efforts are not yet integrated. Japan should gain a comprehensive understanding of space environment risk and establish measures to deal with it, such as by revising the Basic Plan for Space Policy.

With regards to space debris in particular, Japan should coordinate with other countries to encourage the formulation of the Code of Conduct, an international framework for space activities. Furthermore, researchers across the globe are starting to develop technologies to guide large, uncontrollable space debris back down to Earth at a safe location. Japan should use its rendezvous technology and robotics to take the lead in researching and developing a viable space object capture system.

It is imperative to continue monitoring daily space weather as well as watching out for gigantic NEOs that may appear in the future.

In order to execute the above policies, there is an urgent need for Japan to recognize the importance of SSA and define the direction of the country's SSA efforts in a policy paper. Meanwhile, Japan also needs to consider making efforts to train personnel to carry out activities that mitigate space environment risk.

(Original Japanese version: published in May/June 2012)

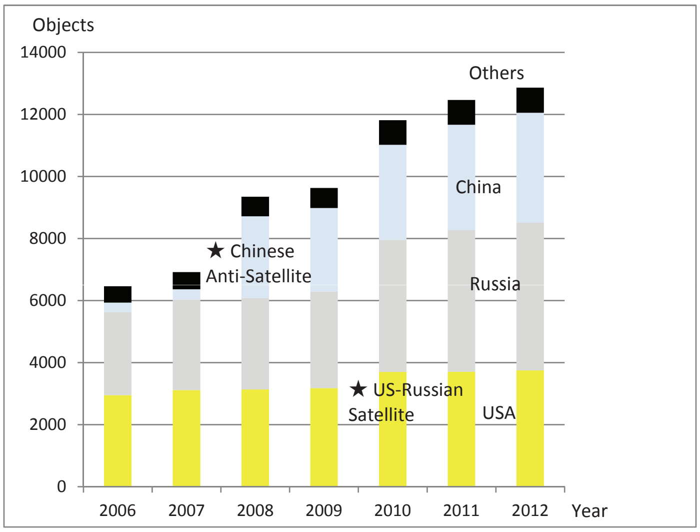

Figure : Rapid Increase in Debris Due to Satellite Destruction and Collisions

Source: Compiled by the Science and Technology Foresight Center from data published every January in the Satellite Situation Report from 2006 through 2012.

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Space Situational Awareness to Mitigate Disastrous Risks from Space

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1 Introduction

In recent years, there has been rising interest in the risk of a disaster produced by the environment in outer space.

Rather than experts in various fields monitoring the space environment independently, the global focus has turned toward broadly educating people across fields about the likelihood of disasters originating in space and ways to counteract them. These efforts are termed Space Situational Awareness. Unlike space surveillance , SSA includes activities to publicize the results of monitoring the space environment.

There are three types of disaster risks posed by the dangers of space on the Earth's surface (hereinafter referred to as "space environment risk"): 1) "space debris" (danger posed to operational satellites and the Earth's surface by a collision/descent of satellites orbiting the Earth at high speed or their fragments), 2) space weather (danger posed to orbiting satellites and ground-based infrastructure by geomagnetic storms, solar wind and other phenomena produced by solar activity) and 3) near-Earth objects (NEOs; the risk of asteroids, comets and other objects in an elliptical orbit around the Sun which intersect with the Earth's orbit).

This paper will address trends concerning research on the hypothetical risks associated with space debris, space weather and NEOs—the main subjects of concern for SSA—and corresponding countermeasures.

2 What is Space Environment Risk?

The October 2004 edition of this journal published a report on the space environment and monitoring its changes. This report provided an overview of measures to monitor, defend against and mitigate the risk posed by space debris, satellite damage due to severe near-Earth space weather produced by the Sun, as well as the likelihood of a near-Earth asteroid collision.[1] Below, this paper will primarily discuss, based on how the situation has changed since then, the state of and danger posed by each type of space environment risk that could lead to a disaster on the Earth's surface.

2-1 Risks of Space Debris

(1) The Situation of Space Debris

According to the Satellite Situation Report[2] issued on January 9, 2012, 38,044 objects have been registered as orbiting the Earth thus far (as of the end of 2011), of which 21,723 have already burned up in the atmosphere. Figure 1 shows the number of objects placed into orbit by Russia, the United States, the European Space Agency (ESA), France, Japan, China and India. Objects flying through space with a diameter of 10 cm or wider are cataloged for the report. There are thought to be hundreds of thousands of smaller pieces of space debris. Because they orbit the Earth at very high speed, nearly 8 km per second, even those with a diameter of 1 cm pose a significant risk in the event of a collision.

According to a study conducted by NASA in 2010, only 10 of the 4,700 space missions conducted since the dawn of space development account for one-third of all cataloged space debris produced. The mission which produced the most debris was an anti-satellite missile test conducted by China against its Fengyun-1C weather satellite (FY-1C, international registration number 1995-025A) on January 11, 2007. By June 2011 it had produced 3,217 pieces of debris, of which 3,078 are still in orbit as of January 2012. This accounts for approximately 24% of flying objects other than orbiting payloads. While it is natural that Russia and the U.S., who have launched far more satellites in the past, account for more space debris than China, the amount of debris added by China's destruction of only one satellite presents an unusual case.

If R represents the number of rocket bodies, D the number of debris produced by satellites (excluding non-operational payloads, although in some cases they are counted as space debris), and S the total objects in orbit, then (R+D)/S shows the proportion of orbiting objects other than payloads. Because China's anti-satellite missile test produced an extremely large amount of debris, the country accounts for an incredibly high percentage of non-payload orbiting objects: about 97%. In contrast, the ESA and Japan account for a fairly low amount of debris when compared to the global average. The U.S., Russia, France and India, among others, are around the global average. It should be noted that at the present moment, we cannot help but increase the amount of orbiting debris produced by payloads because rocket bodies inevitably add to the debris during launch. An issue that countries will need to cooperate on in the future will be controlling the production of space debris—including rocket bodies—and disposing of it safely.

(2) Cases of Highly Dangerous Space Debris

a) Large amount of space debris from an anti-satellite missile test

On January 11, 2007, China tested a missile that destroyed the retired Fengyun-1C (FY-1C) weather satellite. It is thought that the People's Liberation Army (PLA), which launched the missile, believed that there would be no trace of the satellite and that its components would burn up in the atmosphere. However, the satellite's destruction actually vastly increased the number of flying objects in orbit, and most fragments have not disappeared. The space agencies of other countries heaped criticism on China for increasing the danger of space debris collisions. This is because the destroyed satellite's remnants are in a polar orbit at an altitude of nearly 800 km, where many countries' Earth observation satellites revolve around the Earth.

b) Nuclear-powered satellite re-entries and current operations

On January 24, 1978, Cosmos 954, a Soviet maritime reconnaissance satellite, fell on the snowy plains of northwestern Canada. While no people were hurt, Cosmos 954 scattered numerous components contaminated with radiation from the nuclear reactor that powered it. The Canadian government demanded roughly 14 million dollars to pay for the recovery and decontamination. The Soviet Union paid Canada around 3 million dollars as compensation for the damage. By 1988, before the Soviet Union broke up, it had launched 37 satellites with onboard nuclear reactors of the same model, of which five have re-entered the atmosphere and 32 are still in orbit. The U.S. has also launched many satellites equipped with nuclear batteries fueled by plutonium. Some are planetary probes that have traveled far from Earth, but many still orbit our planet. Although none are said to have fallen back to Earth yet, we must continue to monitor them.

Table 1 : Registered Orbiting Objects at End of 2011

Country/ Organization	Orbiting Objects					Objects No Longer Orbiting				Total
	Payloads	Rocket Bodies (R)	Satellite Debris (D)	Subtotal (S)	(R+D)/S*1	Payloads	Rocket Bodies	Satellite Debris	Subtotal	
USA	1112	653	3111	4876	77.2%	794	612	4052	5458	10334
Russia	1457	985	3674	6116	76.2%	2468	2729	8958	14155	20271
ESA*2	48	6	38	92	47.8%	9	7	15	31	123
France*2	55	129	308	492	88.8%	8	62	607	677	1169
Japan	128	43	35	206	37.9%	28	57	140	225	431
China	120	66	3430	3616	96.7%	57	90	556	703	4319
India	50	15	114	179	72.0%	9	10	267	286	465
Others	630	31	83	744	16.0%	61	11	116	188	932
Total	3600	1928	10793	16321	78.0%	3434	3578	14711	21723	38044

Source: Compiled by the Science and Technology Forecast center based on Reference #2.

*1 (R+D)/S represents the proportion of non-payload objects in orbit.

*2 Because European rockets are developed by the ESA and launched by a French company, Rocket Bodies are attributed to the ESA only in the case of ESA satellite launches and are attributed to France when satellites are unrelated to the ESA.

c) Terminated large satellite re-entries

Outside of satellites equipped with nuclear reactors, there is also a great risk of a major disaster caused by the re-entry of a large inoperable satellite. As shown in Figure 2, there has been a series of incidents since September 2011 in which large satellites that have lasted beyond their useful life have re-entered the atmosphere and sent large components flying down from space and towards the Earth at high speed.[3] There is a particularly high risk posed by satellites launched up until the 1990s, when space debris countermeasures were inadequate. The Rossi X-ray Timing Explorer (RXTE) is an American x-ray telescope that is expected to descend in 2014 or later. Figure 2 shows examples of recent and predicted large satellite re-entries.

The risk of disaster posed by these sorts of objects falling from space is one aspect of the burden we bear from increased activity in space. The international community is demanding that space-faring countries take it upon themselves to take sincere safety measures. We especially must not forget that a country which causes a disaster in another one due to a falling satellite is liable for damage under the Outer Space Treaty.

d) Satellite collisions in space

As the number of satellites and space debris increases, so, too, does the likelihood of collisions between flying objects in space. If two satellites collide, then it can cause a major disturbance, even on the Earth's surface. Although there have not yet been any collisions between operational satellites, an operational satellite did hit a non-operational satellite on February 10, 2009, when Iridium 33, a communications satellite operated by U.S. company Iridium Satellite LLC (now Iridium Communications Inc.), was involved in a lateral collision over Siberia with Cosmos 2251, a retired Russian military satellite.

It is very difficult to make advance predictions of satellite collisions. Furthermore, calculating collision predictions enough to prevent all such accidents would require enormous time and expenditures. In Iridium'

Table 2 : Recent Large Satellite Re-entries and Possible Future Re-entries

Owner	Name	Launch Year	Re-entry Date	Landing Site
USA	UARS	1991	Sep 24, 2011	South Pacific
Germany	ROSAT	1990	Oct 23, 2011	Bay of Bengal
Russia	Fobos-Grunt	2011	Jan 15, 2012	Chile Pacific Coast
USA	RXTE	1995	2014 - 2023	-

Source: Compiled by the Science and Technology Foresight Center from various materials.

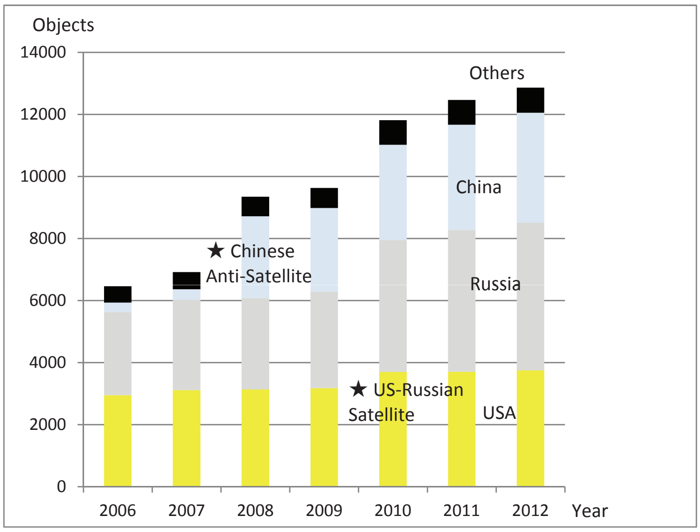

Figure 1 : Rapid Increase in Debris Due to Satellite Destruction and Collisions

Source: Compiled by the Science and Technology Foresight Center from data published every January in the Satellite Situation Report from 2006 through 2012.

s case, it was cheaper to launch a replacement satellite than to predict collisions. Furthermore, because the company operates more than 66 satellites, they can surmise that even if one is lost, they can use a backup, so a collision will not affect communications services.

(3) The Risks of a Continuous Increase in Space Debris

Figure 3 shows the increase in space debris over the past few years. This graph was compiled from space debris figures for the U.S., Russia, China and other countries as posted in the Satellite Situation Report from 2006 through 2012. The amount of Chinese space debris rose sharply in 2007 due to the anti-satellite missile test, while American and Russian space debris jumped up in 2009 after the collision between their satellites. If the amount of space debris continues to increase at the pace set thus far, then we may enter a phase in which space debris collisions create more debris, and thus more collisions, and so on.

In September 2011, the National Academy of Sciences (NAS) and the National Research Council (NRC) released a report recommending that NASA draw up a strategy to deal with space debris and formulate policies to remove debris and lessen the danger. The NRC suggested specific steps for NASA to take: record, analyze, report and share information on spacecraft defects; hold a public debate on space debris; and take initiatives in consideration of the long-term problems for the public.

2-2 The Risks of Space Weather

(1) Space Weather and Space Weather Forecasting

The environment surrounding the Earth is far from quiet: particles and radiation fly about and induce electromagnetic activity to create a highly unstable, variable area. While the Earth's surface is protected because the atmosphere significantly mitigates these dangers, humanity is not entirely unaffected by them. This is why the variable environment around the Earth is called "space weather."

The main indicators for space weather are the speed of solar wind and the amount of plasma. The electrical charge of the plasma in solar wind reacts with the Earth's magnetosphere to produce aurorae over the poles and electrical potential difference (i.e. voltage). While the focus has been on monitoring what can be observed of the situation of the ionosphere and terrestrial magnetism,[1] in recent years, space telescopes have made it possible to observe the Sun and predict solar activity even hours or days in advance.

Space weather forecasting is observing this sort of solar activity and changes in the space environment, predicting space weather and reporting this information to the public via researchers.

(2) Harmful Effects of Space Weather Variability on the Earth's Surface

While a solar maximum that would have a great effect on space weather is predicted for 2013, in early 2012 we are already entering a time when we need to be cautious: for example, large solar flare warnings. Solar weather is worst when it poses a high risk of damaging solar panels on satellites operating in space or harming their internal circuitry. It can also have an electromagnetic effect on power lines and other ground-based equipment.

One example of how a solar flare (an explosive phenomenon on the Sun's surface) can affect satellites occurred in 2006 when a number of ESA satellites had their observation equipment power supplies knocked out. When satellites for practical uses such as communications/broadcasting satellites, Earth observation satellites and navigation/positioning satellites stop functioning, it can have a direct impact on society's infrastructure.

March 6, 2012 witnessed the largest solar flare in the preceding five years, and the National Oceanic and Atmospheric Administration (NOAA) in the U.S. issued a warning that it could affect satellites, radio communications and more.

2-3 The Risks of Near-Earth Objects

(1) The Situation of Near-Earth Objects

Near-Earth object (NEO) is a term mostly applied to near-Earth asteroids (NEAs), comets and meteoroids from other planets that fly in an elliptical orbit intersecting with the Earth's. There are tens of thousands of NEAs among the numerous asteroids between Mars and Jupiter that approach Earth's orbit. Countries are working to understand asteroids that, while they will not strike our planet, may possibly pass within a distance equivalent to that between Earth and the Moon.

In November 2011, an NEA with a diameter of 400 meters passed the Earth at a range equal to four-fifths the distance between us and the Moon. Another asteroid of this size passed nearby 30 years before, and NASA predicts the next to occur in around 2028.

There are a great many smaller NEAs that burn up after entering the Earth's atmosphere. Recently, an example of a near-miss was when the asteroid 2012 BX34 passed the Earth at a distance of approximately 59,000 km on January 27, 2012.

Even smaller meteoroids frequently hit the Earth. They can fetch a high price, as in the case of a meteoroid from Mars that landed in Morocco in January 2012 and was purchased by the University of Arizona.

(2) The Danger of an NEO Strike

If a relatively large NEO happened to strike the Earth, it would cause major changes to the Earth's environment. A large NEA hitting the Earth is the generally accepted explanation for the extinction of the dinosaurs. While these sorts of collisions are incredibly rare, when they do occur, they cause enormous harm to the Earth's living creatures. NEOs must be monitored and data on their trajectories collected in order to quickly determine the risk of an impact. If there was a risk of an NEO hitting the Earth, then we would consider ways of changing the object's trajectory.

3 Space Situational Awareness (SSA) Policy of Space-faring Countries

Major space-faring countries have begun issuing policies on Space Situational Awareness (SSA) in order to reduce space environment risk. Western space related persons became more interested in SSA because of the Chinese missile test in 2007 that destroyed a Chinese own satellite.

The International Code of Conduct (CoC) for Outer Space Activities put forward by Europe is a cooperative international framework to reduce manmade space environment risk. Under this framework, countries with advanced space programs such as the U.S., Europe, Russia, Japan, China and India would coordinate their SSA activities and promote relevant policies to improve on the status quo. This would enhance their ability to deal with naturally occurring space environment risk posed by space weather, NEOs and the like by conducting joint monitoring and sharing information.

The U.S. and Japan delegate the tasks of monitoring and investigating the aforementioned three types of risk between different organizations, and at present the subject of SSA in government policy is confined only to space debris. Europe has created an SSA program budget that deals with both space debris and space weather, but it still does not have integrated SSA policies for NEOs. China first referred to the three types of space environment risk in a 2011 white paper on space.[4] All the major space-faring nations should formulate comprehensive policies to deal with the three types of risk in the future and engage in international cooperation. The state of SSA efforts in each country/region is given below.

3-1 SSA Policy in Europe

(1) The European Space Agency SSA Program

In 2009 the European Space Agency (ESA), a group of 19 European member countries (the most recent being Romania, which joined in 2012) and Canada, its lone associate member, established a budget for SSA to implement space debris countermeasures and space weather forecasting to complement the agency's main programs for launch vehicle/satellite development and manned spaceflight. The size of the budget for the three-year preparatory period started at 9 million euros in 2009, growing to around 10 million euros in 2010 and around 16 million euros in 2011. However, the budget dropped to 15.4 million euros in 2012,[5] a modest amount for the first year of full-scale implementation following the preparatory program.

Up to now, the ESA has set up a telescope in Spain to monitor space debris in geostationary orbit and built a European space weather observation network that should prove useful for SSA activities on into the future.

Right now the ESA treats NEOs as a separate issue from SSA, but there is a proposal to link ground-based facilities, data distribution and the like with SSA.[6]

(2) EU Initiatives

The European Union (EU) and ESA hold a regular meeting of administrators (the ESA Council at Ministerial Level). At the seventh meeting held in November 2011, the participants displayed their awareness of the need to establish SSA response capabilities to protect Europe's space assets.

In March 2011, the European Council (EC) conducted a survey on awareness of the EU's overall space program. Eighteen of the questions were about SSA. There were 608 respondents from 27 countries. First off, the survey found that around 97% of people are aware of the damage that solar flares and space debris cause to satellites. The respondents rated business sectors for how much they are affected by such phenomena on a five-level scale, with a rating of 5 being most highly affected. Those sectors that received many ratings of 4 or higher included aircraft and automobile navigation/positioning systems (73%) and weather forecasting and Earth observation satellites (69%). Furthermore, 57% of respondents said that the EU should make sure it can deal with SSA-related problems.

Meanwhile, the EU has also proposed the CoC, a multilateral cooperative framework to maintain order among the space programs of the world's countries. The CoC is an attempt to win the support of major space-faring countries outside of Europe such as the U.S., Russia and Japan in dealing with the many problems associated with safety in outer space, and to foster a globally shared view of the CoC's guidelines. The U.S. and Australia have already declared that they will be involved in these efforts, while Japanese Foreign Minister Koichiro Genba announced on January 25, 2012 that Japan will participate in the EU-led formulation of the CoC. It is thought that formulating international rules on the development and use of space and implementing them through multilateral cooperation will contribute to mitigating manmade space environment risks.

(3) Initiatives by Individual European Countries

While one distinguishing characteristic of European space activities is that the ESA executes large projects that no one country can undertake alone and that are funded by multiple member states, these activities have a multilayered structure in that the space agencies of individual member states also execute their own domestic space programs. Although member states have conducted SSA-related initiatives on their own, they have not done so jointly.

Examples of these go-it-alone efforts include ROSACE (an optical telescope to monitor geostationary orbits) and TAROT (a telescope to track high-speed objects), managed by France's space agency, the National Centre for Space Studies (CNES); Germany's TIRA (the Tracking and Imaging Radar at FGAN); Norway's Globus (a space monitoring radar); and Sweden's EISCAT (a network of space monitoring radars). All of these facilities have been set up to monitor space debris. The French Air Force also operates a radar network, developed by The French Aerospace Lab (ONERA) to monitor space debris.

In the future, rather than using this two-tiered structure to support each country's equipment and fund the ESA, member states will likely head in the direction of funding the ESA so that it can manage SSA facilities for all of Europe in a balanced, continent-wide manner. Expectations are that each country's equipment will continue operating under a primary center that will allocate roles through a network. Meanwhile, costs will also be cut by closing certain facilities. These and other measures will streamline the continent's SSA efforts.

3-2 SSA as a Component of the New U.S. Space Policy

In the United States, the Department of Defense (DOD) monitors space debris, the National Oceanic and Atmospheric Administration (NOAA), an agency administered by the Department of Commerce (DOC), observes space weather, while the National Aeronautics and Space Administration (NASA), certain universities and other organizations monitor NEOs.

The New National Space Policy announced by the Obama administration in 2010[7] states that the direction of U.S space activities will be to display American leadership in space in order to make it a place that the countries of the world can use peacefully, and to sustain a stable space environment for humanity to obtain the many benefits of outer space. Furthermore, the policy warns that irresponsible behavior in space affects all the people of the world and asks all countries to act responsibly so that posterity will inherit the opportunity to use and explore outer space. Moreover, it promises that the United States will also act responsibly in space. Regarding SSA, the announcement states that the U.S. will focus on space debris caused by human activity, enhance the country's capabilities, and bolster a common view of the issue by working together with other countries and industry.

On January 17, 2012, the U.S. government released a statement declaring that it will work with the EU to formulate an International Code of Conduct for Outer Space Activities in order to build a multilateral framework for the safe development and use of space, with a focus on dealing with space debris.

3-3 Space Debris Measures in Japan's Basic Plan for Space Policy

In Japan, the idea of SSA has not yet taken root in the Basic Plan for Space Policy.[8] The Japan Aerospace Exploration Agency (JAXA) handles space debris monitoring, mitigation measures and the like, the National Institute of Information and Communications Technology (NICT) monitors and forecasts space weather, while the National Astronomical Observatory of Japan (NAO) and incorporated NPOs study NEOs. Japan has not integrated efforts to deal with space debris. The Basic Plan for Space Policy should be revised with an integrated approach to SSA and deal with space environment risk.

The Basic Plan for Space Policy formulated in 2009 names the following three space debris-related issues as subjects that concern the “preservation of the space environment.”

(a) Knowing the Distribution of Debris

While JAXA and other organizations currently monitor debris with their space observation capabilities, they can only distinguish orbiting debris down to a meter in diameter. They do not have a detailed or accurate understanding of sub-meter debris that could destroy a satellite in a collision. In the future, JAXA wants to work with observational data from other countries with the goal of understanding exact orbital positions and other characteristics of sub-meter debris.

(b) Minimizing the Creation of Space Debris

Effective ways to minimize the creation of space debris are to keep components from flying off of operational satellites and to prevent retired satellites from exploding. In Japan, JAXA drafts its own guidelines to reduce debris, with which it strictly complies. Japan is promoting the preservation of the space environment by making sure to address the matter internationally, such as by actively participating in the creation of an international framework to reduce the amount of debris created. Japan is also pushing ahead with research on measures to protect satellites from debris, and on satellites that would limit ground damage after re-entering the atmosphere upon retirement.

(c) Steps to Remove Debris

The Inter-Agency Space Debris Coordination Committee (IADC) and others point out the possibility that an increase in the amount of debris could lead to collisions between these objects, thus leading to a natural increase in the number of objects making up the debris. In Japan, the technology to capture debris or remove it from orbit (e.g. robots to capture debris and other technology) is still in the research phase. In the future, Japan will continue working with international partners, while promoting research with the goal of using small satellites and such to demonstrate technology to capture debris or remove it from orbit.

3-4 SSA Policy in the Chinese Space White Paper

In the year 2011, China surpassed the U.S. by launching 19 rockets, second in the world only to Russia. The U.S. and Europe have warned China about SSA as the country has quickly ramped up its space program. In December 2011, around the start of China's twelfth Five-Year Plan (2011-2015), the country published “China’s Space Activities in 2011,” that year’s edition of its space white paper. It made mention of initiatives related to space debris, space weather and NEOs alongside major projects such as manned spaceflight and lunar exploration. The paper describes specific plans for countermeasures against space debris in particular. When we remember that the reason for the West’s heightened interest in SSA is the missile test China conducted to destroy one of its own satellites, we can interpret China’s positive space debris-related efforts as a response to the West’s reaction. If the white paper is a statement that China will not repeat the action that produced the massive amount of space debris from its anti-satellite missile test, we should welcome China taking a step towards coordinating with the international community.

4 Space Environment Risk Countermeasures

Nowadays, many more countries recognize the existence of space environment risk. They should deal with this risk based on sound government policy.

What the three types of risk have in common is that we need to first set up arrangements for monitoring targets and then develop the technical capabilities to deal with each type.

4-1 Space Debris Countermeasures

At present, many countries are monitoring or taking steps to protect against and minimize space debris. As yet, very few measures have been taken to remove particularly dangerous large debris.

(1) Space Debris Monitoring

The U.S. constantly monitors space debris of at least a certain size. U.S. Strategic Command (Stratcom) tracks 800 satellites and over 20,000 pieces of space debris in regular operation, and releases tracking informations to other countries as possible as it can. Even so, there is a great deal of untracked space debris because Stratcom is significantly lacking in personnel to track all objects flying around the Earth that could affect a satellite. Additionally, there is no country tracking satellites more than the U.S. does.

Japan has also been relatively quick to set up and operate its own monitoring facilities. JAXA uses the space debris monitoring facility in Okayama Prefecture owned by the Japan Space Forum (JSF) to keep a daily visual watch on space debris in geostationary orbit, determine the trajectories of satellites in low-Earth orbit and conduct other monitoring. However, six to eight years have passed since the JSF facility was completed and its performance is inadequate. An issue warranting examination is how to beef up JAXA's monitoring capabilities through international collaboration in order to add more monitoring facilities or improve performance.

However, Europe, Russia, China and others monitor objects flying through space visually and with radar, allowing each to collect its own data that takes advantage of each country's geographical traits. More international cooperation in monitoring should take place to supplement the limits of U.S. monitoring capabilities.

(2) Measures to Protect the Space Station and Satellites from Space Debris

NASA runs a program that examines measures to protect the Space Station and satellites for practical use from space debris. The program's central office is at the Johnson Space Center (JSC) in Houston, Texas.[9] NASA's greatest concern regarding space debris protection is the threat to the safe operation of the International Space Station (ISS), where three to six astronauts are onboard at any time. The structure of the ISS protects it from particle-sized debris collisions with bumpers, but it has to regularly raise or lower its trajectory to avoid medium-sized and large space debris. The thrust generated by Russian and European supply ships docked at the ISS is used to change the station's trajectory.

(3) Measures to Reduce Space Debris

In February 2007, the General Assembly of the United Nations adopted the Space Debris Mitigation Guidelines, recommended by the IADC, as a measure to reduce the amount of space debris. Countries that launch satellites are taking the necessary steps to reduce space debris in accordance with these guidelines. Of course, Japan is developing satellites based on the guidelines and taking measures to deal with space debris.

China, which is becoming a major space-faring nation alongside the U.S. and Russia, is involved with the IADC, where it cited its steps to reduce the amount of space debris produced by satellites and launch vehicles in its 2011 Chinese space white paper. An example of China taking proactive steps to reduce space debris is its operating plan for the Tiangong-1 space station launched in September 2011. After three Shenzhou spacecraft dock with Tiangong-1 and it completes its two-year mission, the plan calls for the space station to re-enter the atmosphere over a safe location.

(4) Development of Space Debris Removal Technologies to Avoid Satellite Re-entries

The safest way to deal with the risks associated with a satellite re-entering the Earth's atmosphere is to remove it before it descends on its own. There are many ideas about how to do this, including the use of a suction device to capture it or employing lasers to alter its trajectory. A satellite can be forced to re-enter the atmosphere in a planned manner that lands it in a safe place. This can be done by launching a chaser satellite controllable from the ground that will capture the target satellite. After docking, the chaser satellite is directed by its ground-based operator to use its thrust to maneuver it and the target satellite into a new re-entry trajectory.

In February 2012, a Swiss university published an idea of developing a 1-kilogram capture satellite to conduct an experiment to seize a miniature satellite (also 1 kg) already in orbit and burn it up in the atmosphere. Although the size of the satellites is small, the idea received intense media coverage as a concrete example of how we might deal with space debris. The Innovative Technology Research Center, part of JAXA's Aerospace Research and Development Directorate in Japan, is conducting R&D on technology for a system that would capture space debris and dispose of it from orbit. This idea has been around since the 1990s, when an entry to the annual Satellite Design Contest in Japan proposed using a chaser satellite to capture a target satellite with a suction cup-equipped arm, similar to the mechanism employed by an octopus' tentacle. Japan would likely make a major contribution to the world's development of space if it can safely remove space debris by employing its expertise in rendezvous technology and robotics.

4-2 Monitoring and Responding to Space Weather Fluctuations

For a long time now, we have been learning about space weather through indirect means such as monitoring geomagnetism over our planet or observing the situation of the ionosphere. This mainly used to focus on dealing with noise in radio communications and the like, but now space weather has a significant effect on essential components of our infrastructure: satellites, aircraft, power lines, pipelines and more. Thus, we now have to take steps to protect satellite solar panels and electronics from harm posed by space environment risks.

(1) Monitoring by Solar Observation Satellites

Our capabilities to observe the Sun with satellites have improved to provide early warning of changes in the solar activity. In recent years, the standard practice has been to place solar observation satellites at Lagrangian points to directly monitor solar activity and predict changes in solar weather.

Figure 4 shows what is being observed by U.S, European and Japanese solar observation satellites. The observational data from U.S and European satellites placed at particularly gravitationally stable Lagrangian points (L1, L4 and L5) is used effectively for monitoring solar activity. The two STEREO satellites monitor the Sun from its sides at positions ahead and behind the Earth in its orbit, thus enabling NASA to predict, according to the Sun's rotation, when enhanced activity will affect the Earth. Data from Hinode, the Japanese solar observation satellite, has also contributed to global efforts to monitor space weather.

(2) Space Weather Forecasting Sites of Various Countries

At present, the 13 major space-faring nations have set up websites providing up-to-date space weather forecasts for the general public. All of them operate in a partnership with the International Space Environment Service, an organization within the United Nations Educational, Scientific and Cultural Organization (UNESCO).

a) United States of America

In the U.S., NOAA's Space Weather Prediction Center (SWPC) uses data from its GOES geostationary satellites to compile information for space weather forecasting. The SWPC website publishes daily information on observations and predictions.[10]

Table 4 : Main Solar Activity Observation Satellites

Name	Owner/ Operator	Orbit	Mission	Launch Year	Subject of Observation
GOES	USA/NOAA	Geostationary	Weather Observation	1994 onward	Solar X-ray images, X-rays, protons (hydrogen ions), electrons
SOHO	ESA/NASA	L1	Solar Observation	1995	Coronal mass ejection (CME)
STEREO	USA/NOAA	L4 & L5	Solar Observation	2006	Lateral solar activity
Hinode	Japan/JAXA	Polar Orbit	Solar Observation	2006	Coronal holes on Sun's surface

Source: Compiled by the Science and Technology Foresight Center from various materials.

The top page shows the latest image of the Sun, along with the degree of geomagnetic storms, solar radiation storms and radio blackouts. Geomagnetic storm forecasts use a six-level scale indicating the disturbance they will create: None, Minor, Moderate, Strong, Severe and Extreme. Similarly, the site uses a six-level scale for particle/ion density in the event of solar storms of 10 MeV or greater and, if radio blackouts are forecast, the maximum luminosity of solar X-rays.

b) Europe

The ESA mainly forecasts space weather by releasing images of the Sun taken by the Solar & Heliospheric Observatory (SOHO), a joint ESA-NASA project, at the ESA Space Weather Web Server.[11] However, compared to other country's websites, this one's weather forecasts are tailored more for experts. It does not provide easily understandable indicators as NOAA does.

c) Japan

The NICT publishes daily observational information at the Space Weather Information Center (SWC) website, with sources including U.S. satellites and Hinode, the Japanese solar observation satellite.[12] The top page uses graphics to provide a summary of observational information.

Furthermore, the Space Weather News website provides more accessible information for the general public with daily space weather forecasts in a format closely resembling terrestrial weather forecasts.[13]

d) China

The National Space Weather Monitoring and Warning Center, which belongs to the National Satellite Meteorological Center, publishes information on its website that includes three-day space weather forecasts.[14]

e) Russia

The Space Research Institute (IKI) of the Russian Academy of Sciences (RAN) runs a space weather forecast service. Established in 1965, the IKI was involved in Mars and Venus space probe projects, but now it conducts observations of the Earth and scientific research on near-Earth space to study its effects on ecosystems and elsewhere. Part of this work is the research on and the distribution of information about space weather forecasts. The IKI website's content includes data on geomagnetic storms.[15]

(3) Countermeasures by Satellite Operators Using Space Weather Forecasts

Government organizations and companies that operate satellites (e.g. communications/broadcasting, weather, navigation/positioning satellites) providing us with important information every day reference the space weather forecasts provided by various countries and control their satellites to protect them from threats such as geomagnetic storms.

Based on this information, the countermeasures they take include changing a satellite's orientation so that the surface of its solar panels are not facing towards a geomagnetic storm, or putting the entire satellite into an energy-conserving safe mode to maintain minimal functionality.

In addition, the International Space Station is moved to a safer location when space weather poses a potential health hazard to the astronauts on board.

Space weather can affect the Earth's surface as well as outer space. For example, power utilities pay attention to space weather to avoid the danger of irregular currents in power lines caused by electromagnetic induction.

Other than the above, astronomers, amateur radio operators and others also pay attention to fluctuation in space weather.

Table 5 : Main NEA Monitoring Facilities

Name	Operator	Country	Main Telescope Caliber	Number of Asteroids Monitored
NEAT	NASA	USA	1 m	11,000+
Spacewatch	University of Arizona	USA	1.8 m	20,000+
Bisei Spaceguard Center	Japan Space Forum	Japan	1 m	~ 5500

Number of asteroids monitored is current as of February 2012.

4-3 Near-Earth Object Monitoring and Safety Measures

(1) NEO Monitoring by Various Countries

A number of countries monitor NEOs with observatories and satellites. The Near Earth Objects-Dynamic Site (NEODyS)[16] is a website that lists all of the world's observatories and telescopes that are now monitoring asteroids and comets or have done so in the past. It also allows visitors to view data on near-Earth asteroids (NEAs) observed the day before. However, there are not many satellites that can find NEAs efficiently. Figure 5 shows what kind of NEA monitoring takes place at major facilities in the U.S. and Japan.

NEODys lists 109 Japanese observatories and personal telescopes distributed across 30 of the country's prefectures. The Bisei Spaceguard Center in Okayama Prefecture is the most active NEO monitoring site. The center uses data from a telescope with a caliber of 1 meter and equipped with a CCD camera to observe space debris in geostationary orbit. It can also detect NEAs. However, most NEO monitoring in Japan is currently performed voluntarily by NPOs and civilians. To properly monitor NEOs, the country needs to set up an official monitoring infrastructure.

(2) Measures to Deal with NEOs that May Strike the Earth

Even if we could monitor the trajectories of all NEAs and comets and determine the existence of any NEOs that might strike the Earth and when, at present there are very few concrete measures we could take in response. However, there are investigations already underway on how to possibly avoid a collision.

In December 2009, a committee formed by the Russian Federal Space Agency (FSA) to investigate ways of avoiding a possible collision with the asteroid Apophis in 2036 published a plan to do so. There are worries that Apophis, with a diameter of 350 meters, could turn 500,000 square kilometers of land into desert were it to strike the Earth.[17] Some method of altering the asteroid's trajectory would be necessary to avoid a collision. Because this would require the development of equipment especially for this purpose, the committee suggested that this could become an international project.

While NASA, based on earlier data, announced that Apophis had a small 1 in 45,000 chance of an impact on Earth on April 13, 2036, a recalculation of Apophis' trajectory using the latest data has revised the likelihood of a collision down to 1 in 250,000.

The technology described earlier in this paper to safely capture space debris and make it re-enter the Earth's atmosphere may help us develop the technology needed to deal with a dangerous asteroid like Apophis in the future by altering its trajectory.

5 What Japan Should Do Next

Japan also needs to put more effort into mitigating space environment risk by having an active Space Situational Awareness (SSA). Given the monitoring that is conducted now, we cannot entirely rule out this risk. We must recognize that it could pose a grave threat to humanity's existence and to society's infrastructure.

However, while Europe, the U.S., China and others are working out policies formulated with an awareness of SSA, the concept itself has still not taken root in Japan. Different organizations and research groups deal with the three types of space environment risk, but they are not in fact exclusive of each other. For example, if Japan developed space environment observation satellites that can monitor space debris, solar weather and NEOs and had multiple groups collaborating by sharing observation data, then we could expect that to have a synergistic effect. To do this, Japan should gain a comprehensive understanding of space environment risk and establish measures to deal with it, such as by revising the Basic Plan for Space Policy. With regards to space debris in particular, Japan should coordinate with the U.S., Europe, Russia, China and others to encourage the formulation of the Code of Conduct, an international framework for space activities.

Japan needs to continue engaging in each of the following concrete activities to deal with the three types of space environment risk.

(1) There are limits to the capabilities of the U.S., the current leader in this field, to track the growing amount of space debris. Each country should contribute to the effort by taking advantage of its own geographical traits and technical capabilities. While of course Japan is developing satellites in compliance with its Space Debris

Mitigation Guidelines, the country should be proactive and take the global lead, such as by setting up monitoring facilities and developing debris mitigation technology. On the technical front, Japan should especially upgrade current performance in optical and radar observation.

(2) Japan also has new opportunities worldwide to research and develop technologies to capture large, uncontrollable space debris and bring it back to Earth in a safe location. Japan should employ its advanced rendezvous technology and robotics to research and develop a viable space object capture system.

(3) Space weather forecasts are now essential information to protect satellites for practical use that are integrated with society's infrastructure, as well as to protect ground-based facilities from adverse effects. These forecasts are needed to guarantee the continued operation of these public services.

(4) While the improved performance of observational equipment such as optical telescopes and CCD cameras has made the monitoring of NEOs more efficient, Japan needs to build a monitoring infrastructure (e.g. training relevant personnel) and operate it on a continual basis. In addition, measures to prevent a giant NEO from possibly striking the Earth in the future would likely be examined as an collaborative, international endeavor, so Japan should bring along its advanced technological prowess while actively participating in international partnerships.

In order to execute the above policies, there is an urgent need for Japan to first understand what the world is doing about SSA and know what the country needs to do, and then define the direction of Japan's SSA efforts in a policy paper. Meanwhile, Japan also needs to consider making efforts to train personnel to carry out activities that mitigate space environment risk.

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